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(54) Title: SINGLE CHAIN T-CELL RECEPTOR

(57) Abstract

Disclosed is a single chain T-cell receptor which binds specifically to an MHC peptide ligand. The single chain T-cell receptor is a 3-domain construct comprising an  $\alpha$  chain variable domain, a  $\beta$  chain variable domain and a constant domain. Also disclosed is a self-signaling single chain T-cell receptor which binds specifically to an MHC/peptide ligand and mediates signal transduction.

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SINGLE CHAIN T-CELL RECEPTORGovernment Support

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Background of the Invention

10 T-cell receptors (TCRs) are recognition molecules  
present on the surface of T lymphocytes. Although  
closely related to antibody molecules, T-cell receptors  
have numerous properties which distinguish them from  
antibodies. One fundamental difference between T-cell  
receptors and antibody molecules is that antibody  
15 molecules exist in two alternative forms: cell surface  
molecules or soluble secreted molecules. Native T-cell  
receptors exists, however, only as cell surface  
molecules.

20 The T-cell receptors which are found most commonly  
on the surface of T-cells are comprised of two  
glycoprotein subunits which are referred to as the  $\alpha$  and  
 $\beta$  chains. Both chains have a molecular weight of about  
40 kDa and possess a variable and a constant domain.  
The genes which encode the  $\alpha$  and  $\beta$  chains are organized  
25 in a manner which is similar to antibody gene  
organization in that there are libraries of V, D and J  
regions from which the genes are formed by genetic  
rearrangement.

30 TCRs recognize antigen which is presented by an  
antigen presenting cell as a part of a complex with a  
specific self-molecule encoded by a histocompatibility  
gene. The most potent histocompatibility genes are  
known as the major histocompatibility complex (MHC).  
The complex which is recognized by T-cell receptors,  
35 therefore, consists of and MHC/peptide ligand.

The ability to produce a soluble T-cell receptor  
which retains specificity for an antigenic peptide  
presented by an antigen presenting cell as a component  
of a complex including the MHC is useful in a variety of

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contexts which are discussed in greater detail below. Several approaches have been employed to produce soluble, recombinant T-cell receptors. In these recombinant T-cell receptor molecules, the  
5 transmembrane/cytoplasmic regions of the  $\alpha$  and  $\beta$  chains were replaced with sequences from lipid-linked proteins (GPI anchor), the CD3- $\gamma$  chain or with immunoglobulin (Ig) heavy or light chains. Soluble T-cell receptors were recovered either as secreted proteins (Ig  
10 constructs) or obtained by enzymatic cleavage of the GPI-anchor or the CD3- $\gamma$  chain. All of these approaches rely, however, on the assembly of the heterodimer which is inefficient. In addition, high level expression of the human T-cell receptor  $\alpha$  chain in transfected  
15 eukaryotic cells is not stable.

These problems can be avoided by the design of a single chain recombinant protein in which the variable regions of the heterodimer are joined by a short peptide linker. Such a design has been successfully applied to  
20 antibody molecules. Such recombinant molecules, known as single-chain Fv's, have a specificity similar to that of native antibodies. Several groups have reported the production of single chain T-cell receptors in bacterial expression systems using the single chain antibody (Fv)  
25 design. However, due to the lack of functional data from these reports, it is unknown and impossible to predict whether the single chain Fv design yields soluble T-cell receptors that recognize the MHC/peptide ligand.  
30

#### Summary of the Invention

The present invention relates in one aspect to a single chain T-cell receptor which binds specifically to an MHC/peptide ligand. The single chain T-cell receptor of the present invention has been demonstrated to be soluble in aqueous media. In a preferred embodiment, the single chain T-cell receptor is a 3-domain single  
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chain T-cell receptor comprising an  $\alpha$  chain variable domain ( $V\alpha$ ), a  $\beta$  chain variable domain ( $V\beta$ ) and a constant domain. Specifically disclosed is a single chain T-cell receptor wherein the  $V\alpha-J\alpha$  domain of the  $\alpha$  chain variable domain is linked to the N-terminus of the  $\beta$  chain variable domain by a flexible amino acid linker and the C-terminal region of the  $\beta$  chain variable domain is linked to the  $\beta$  chain constant domain ( $C\beta$ ).

In another aspect, the invention relates to a self-signaling single chain T-cell receptor which binds specifically to an MHC/peptide ligand. The self-signaling T-cell receptor is preferably comprised of: 1) a soluble T-cell receptor domain comprising an  $\alpha$  chain variable domain, a  $\beta$  chain variable domain and a constant domain; and 2) a transmembrane and intracellular signaling domain from a transmembrane receptor. When displayed on the surface of a T-cell, the self-signaling T-cell receptor has the ability to transduce signal following specific binding to MHC/peptide ligand.

The invention also relates to nucleic acid molecules which encode the single chain T-cell receptors described above, expression vectors containing such nucleic acid molecules, and cells which carry expressible copies of such nucleic acid molecules. In addition, the invention relates to methods for diagnosing viral infection in a patient. Disclosed are methods which employ both the single chain T-cell receptor, and the self-signaling embodiment of the single chain T-cell receptor.

Brief Description of the Drawing

Figure 1 is a diagrammatic representation of T-cell receptor  $\alpha$ - and  $\beta$ -chain genes and various chimeric constructs which employs the following designations: S-S, disulfide bond; L, leader; V, variable segment; J, joining segment; C, constant region; TM, transmembrane

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region; Cy, cytoplasmic region; ATG, start codon; Li, 15-residue peptide linker containing three repeats of GGGGS; PI, GPI domain of human placental alkaline phosphatase with the sequence

5 LAPPAGTTDAAHPGRSVVPALLPLLAGTLLLL (SEQ ID NO. 3). The  $\zeta$  region contains transmembrane and cytoplasmic domains of the marine CD3  $\zeta$  chain starting at position 31 (Engel et al., *Science* 256: 1318 (1992)).

10 Detailed Description of the Invention

The present invention is based on experiments which resulted in the synthesis of a single chain T-cell receptor which binds specifically to a predetermined MHC/peptide ligand which is presented by an antigen presenting cell (e.g., a macrophage). The MHC component of the MHC/peptide ligand can be Class I or Class II. The term "single chain" is used to describe an amino acid copolymer having a single N-terminus and a single C-terminus. This single chain T-cell receptor is to be contrasted with the native T-cell receptor which is comprised of two glycoprotein subunits which are referred to as the  $\alpha$  and  $\beta$  chains. Another distinction between the single chain T-cell receptor of the present invention, and the native T-cell receptor, is that the single chain T-cell receptor of the present invention is soluble in an aqueous medium. The term "aqueous medium", as used herein, includes, for example, physiologically compatible buffered solutions. It has been determined, for example, that the single chain T-cell receptor of the present invention is soluble in phosphate buffered saline up to a concentration of 1 mg/ml.

As discussed above, the native T-cell receptor is comprised of two glycoprotein subunits which are referred to as the  $\alpha$  and  $\beta$  chains. Each of the glycoprotein subunit chains comprise two domains, one variable and one constant. Like antibodies, the

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glycoprotein subunits are encoded by genes which are formed by rearrangement of segments (V, D and J segments ( $\beta$  chain), and V and J segments ( $\alpha$  chain)) from libraries found in discrete chromosomal regions.

5        In a preferred embodiment of the present invention, the single chain T-cell receptor is a 3-domain single chain T-cell receptor comprising a leader sequence and an  $\alpha$  chain variable domain, a  $\beta$  chain variable domain and a constant domain. While the order of these domains  
10      within the single chain T-cell receptor may be interchangeable, the preferred ordering of the domains is specified below. Such a molecule can be prepared in a variety of ways. For example, conventional synthetic techniques may be employed to produce the desired amino  
15      acid copolymer from its component amino acids (see e.g., Houghton et al., *Proc. Natl. Acad. Sci. USA* 82: 5135 (1985)).

20      Preferably, DNA encoding the single chain T-cell receptor is generated at the genetic level by combining elements from isolated T-cell receptor genes by recombinant DNA techniques (see e.g., Maniatis et al., *Molecular Cloning: A Laboratory Manual*, Cold Spring Harbor Laboratory, Cold Spring Harbor, NY (1982)). In order to practice such methods it is first necessary to  
25      isolate nucleic acid which encodes the  $\alpha$  and  $\beta$  chains of the T-cell receptor having the desired specificity. The generation of DNA encoding the  $\alpha$  and  $\beta$  chains which comprise a T-cell receptor which binds specifically with a predetermined epitope of the human myelin basic  
30      protein (MBP), when presented in association with an MHC Class II protein, is described in detail in the Examples which follow. The procedures specified in connection with the isolation of DNA encoding a T-cell receptor specific for an epitope of the human MBP are applicable  
35      to the isolation of T-cell receptor genes which encode a T-cell receptor which binds specifically to any predetermined MHC/peptide ligand.

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Briefly, an initial step in obtaining DNA encoding T-cell receptor genes which encode a T-cell receptor which binds specifically to any predetermined MHC/peptide ligand is to isolate an antigen specific T-cell clone from a mammal (preferably a human) which is known to possess the antigen of interest in its tissue. For example, if the predetermined MHC/peptide ligand contains a peptide representing a T-cell epitope from an HIV virus, an individual infected with the virus would 10 be selected.

A peripheral blood cell preparation is obtained from the selected individual by conventional techniques (Wucherpfennig et al., *Science* 248: 1018 (1990); Wucherpfennig et al., *J. Immunol.* 152: 5581 (1989)).

15 The peripheral blood cell population is stimulated by contacting the cells with the predetermined antigen using conventional techniques intended to expand the population of T-cells which bind specifically to the antigen of interest. Typically stimulation is carried 20 out with a purified peptide known to contain a T-cell epitope, or with an enzymatically degraded protein preparation (e.g., a partial trypsin digest) comprising a mixture of peptides. This stimulation procedure enriches the T-cell population for those T-cells which 25 specifically bind to an epitope of the antigen of interest. Through dilution, expansion and binding studies, a clonal population of cells encoding a single T-cell receptor specific for the antigen of interest is isolated.

30 DNA encoding the  $\alpha$  and  $\beta$  chains which comprise a T-cell receptor is then prepared from the clonal T-cell population using spliced mRNA as template. One way in which this can be accomplished is through the construction of a cDNA library from a clonal cell 35 culture of the type described above. The isolation of mRNA and the synthesis and cloning of double stranded cDNA molecules encoded by the mRNA is a routine

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procedure (see e.g., Maniatis et al., *Molecular Cloning: A Laboratory Manual*, Cold Spring Harbor Laboratory, Cold Spring Harbor, NY (1982)). The cDNA library is then screened using probes specific for the constant region 5 of the T-cell receptor  $\alpha$  or  $\beta$  chains (see e.g., Davis et al., *Nature* 334: 395 (1988)).

A variety of alternative approaches can also be used to prepare DNA encoding the  $\alpha$  or  $\beta$  chains from mRNA isolated from a cell culture demonstrating the desired 10 binding specificity. Such methods include the use of a standard PCR protocol using first-strand cDNA template prepared from the isolated mRNA. The latter method is, in fact, the method which was used to generate DNA encoding the  $\beta$  chain in the experiments described in 15 detail in Example 1 which follows. Yet another alternative is the anchored PCR technique described by (Loh et al., *Science* 243: 217 (1989)). Using standard recombinant DNA techniques, a 3-part single chain T-cell receptor of the type described herein can be assembled 20 from domains isolated from the  $\alpha$  and  $\beta$  chain DNA.

A leader sequence must be included for proper intracellular processing of the single chain T-cell receptor. In genomic DNA, a leader sequence is always linked to the DNA encoding the  $\alpha$  chain variable domain such that in the encoded product, the leader sequence is 25 located at the N-terminus. Therefore, in the T-cell receptor of the present invention, a leader sequence is located at the N-terminus of the molecule and is considered to be an element of the  $V\alpha$  domain. It will 30 be recognized, however, that although a specific leader sequence is linked to a specific  $V\alpha$  domain in genomic DNA, leader sequences can be exchanged using recombinant DNA techniques without a detrimental affect on the intracellular processing of the encoded fusion. Thus, 35 in the T-cell receptor of the present invention, the  $V\alpha$ - $J\alpha$  domain of the  $\alpha$  chain variable domain is linked to C-terminus of a leader sequence.

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The Va-J $\alpha$  domain of the  $\alpha$  chain variable domain is also linked to the N-terminus of the  $\beta$  chain variable domain by a flexible amino acid linker and the C-terminal region of the  $\beta$  chain variable domain is linked 5 to the  $\beta$  chain constant domain. In addition to these domains which must be present at a minimum, it may be possible to add additional segments without interfering with the essential properties of the encoded molecule.

10 The identity of individual amino acids in the amino acid linker, and the number of amino acids which comprise the amino acid linker are variable. The purpose of this linker is to provide sufficient flexibility within the molecule to enhance the binding characteristics of the soluble T-cell receptor.

15 Typically a linker comprised of about 10 to 30 amino acid residues would be considered sufficient. With regard to the identity of the amino acids in the linker region, glycine is preferred in light of the fact that a glycine polymer exhibits increased flexibility relative 20 to other mono-amino acid polymers due to the fact that it lacks  $\beta$ -carbons. In addition, amino acids which tend to increase solubility in an aqueous solution are preferred (e.g., serine, glutamine, aspartic acid, arginine, etc.).

25 It will be recognized by those skilled in the art that conservative amino acid substitutions introduced (e.g., by site directed mutagenesis) within the constant region may be tolerated without adversely affecting the binding specificity of the T-cell receptor.

30 Furthermore, the framework of a T-cell receptor variable region (i.e., the portion of the variable region other than the CDRs) can be exchanged with corresponding variable regions from other T-cell receptors without adversely affecting the specificity of the receptor.

35 In addition, it will also be recognized that such conservative substitutions may be tolerated within the variable regions so long as they do not occur within a

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complimentarity determining region (CDR), which is sometimes referred to as the hypervariable region. In addition, the scope of the present invention is intended to encompass derivatives of the T-cell receptor of the 5 invention wherein the addition of the derivatizing group would not be expected to substantially alter the binding characteristics of the soluble T-cell receptor. Such modifications include, for example, the addition of a radiolabel group or the conjugation of a toxin molecule.

10 The term "conservative substitution", as used herein, refers to the substitution of a second amino acid residue for a first amino acid residue, both residues having an R group exhibiting substantially similar chemical properties. Standard biochemistry textbooks 15 provide groupings of amino acid residues according to substantial similarity in R group chemistry.

DNA encoding the single chain T-cell receptor, produced in the manner described above, can be expressed in eukaryotic or prokaryotic cells by placing the DNA 20 under the control of regulatory sequences appropriate for expression in the cell type of interest, and introducing the construct into the cell type of interest. Regulatory sequences appropriate for expression can exert their influence at many levels 25 including, for example, the transcriptional, translational and post-translational levels. The DNA encoding the single chain T-cell receptor, together with appropriate regulatory sequences are typically carried within a larger DNA molecule (often referred to as an 30 expression construct) which facilitates the introduction and expression of the expressible nucleic acid encoding the single chain T-cell receptor. An extrachromosomal plasmid is an example of an expression vector which could be used to facilitate prokaryotic expression.

35 Modified eukaryotic viral DNA capable of integrating into the chromosome of a host-cell is an example of an expression vector which could be used to facilitate eukaryotic expression. The selection of expression

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vectors and appropriate regulatory signals is highly dependent upon the particular application. Given a particular experimental goal, the choice of an appropriate vector and appropriate regulatory sequences 5 would be clear to one of skill in the art based on fundamental and well established principles.

In another embodiment, the present invention relates to a self-signaling single chain T-cell receptor which binds specifically to an MHC/peptide ligand when presented by an antigen presenting cell. The native T-cell receptor is not a self-signaling molecule. Rather, the signaling function of the native T-cell receptor is mediated by a number of ancillary proteins. Briefly, there are two major classes of T-cells: cytotoxic T 10 lymphocytes (CTLs) and helper T ( $T_h$ ) lymphocytes. CTLs have the ability to lyse cells which display a foreign antigen on their cell surface (in association with an MHC component).  $T_h$  lymphocytes, on the other hand, recognize the degradation products of foreign antigens 15 and, in response, secrete stimulatory factors which induce response by other immune system components. CTLs can be distinguished from  $T_h$  lymphocytes based on the presence of certain surface proteins. More specifically, CTLs typically have the CD8 protein on 20 their cell surface while  $T_h$  lymphocytes typically have CD4 protein on their cell surface.

The interaction between the antigenic peptide/MHC complex on an antigen presenting cell, and the T-cell receptor on the T-cell, is thought to involve either a class I MHC-CD8 interaction or a class II MHC-CD4 25 interaction. A variety of other proteins also participate in the effector signaling process which results ultimately in the secretion of protein factors by both classes of T-cells (the secreted protein factors include, for example, factors which induce cell lysis in the case of CTLs, and lymphokines in the case of  $T_h$  lymphocytes). Other proteins which participate in the 30 signaling process include, for example, the CD3 complex

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of proteins which are tightly bound to the T-cell receptor, as well as a tyrosine kinase protein encoded by the *lck* gene which is bound to both CD4 and CD8. In summary, the specific interaction of an antigenic peptide/MHC complex with a native T-cell receptor triggers a complex signaling process involving multiple protein participants which results ultimately in the secretion of certain protein factors which play a role in the immune response.

The self-signaling T-cell receptor of the present invention differs from the native form in that a signaling domain is incorporated as a component of the fusion protein. More specifically, the self-signaling T-cell receptor of the present invention includes all of the elements of the single chain T-cell receptor described above (i.e., an  $\alpha$  chain variable domain, a  $\beta$  chain variable domain and a constant domain) as well as a transmembrane and intracellular signaling domain from a transmembrane receptor. As discussed previously, a leader sequence is essential for intracellular processing and is located at the N-terminus of the molecule. The C-terminus of the leader sequence is linked to the N-terminus of the  $V\alpha-J\alpha$  domain of the  $\alpha$  chain variable domain. This, in turn is linked at its C-terminus to the N-terminus of the  $\beta$  chain variable domain by a flexible amino acid linker. The C-terminal region of the  $\beta$  chain variable domain is linked to the  $\beta$  chain constant domain and the C-terminal region of the  $\beta$  chain constant region is linked to the N-terminal region of the transmembrane and intracellular signaling domain from a transmembrane receptor. As was discussed above in connection with the non-signaling single chain T-cell receptor, construction of the self-signaling single chain T-cell receptor is preferably carried out at the genetic level although alternative methods are well known in the art. DNA encoding the transmembrane/signaling domain of the transmembrane

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receptor is also isolated according to well established experimental steps protocols including, for example, standard PCR.

The identity of the transmembrane receptor from which the transmembrane and intracellular signaling domain is derived depends upon the nature of the signal which is preferred. For example, if it is desired that self-signaling T-cell receptor is to be displayed on the surface of a T-cell with the ultimate goal being the stimulation of a response which mimics the T-cell response *in vivo* (e.g., secretion of protein factors such as lymphokines (T<sub>H</sub> lymphocytes) or factors which induce cell lysis (CTLs)), the preferred transmembrane and intracellular domains are derived from the CD3  $\gamma$  chain. A more detailed discussion of the use of this signaling domain in a specific experimental context is provided in Example 1 which follows. In addition, other signalling domains such as the transmembrane and intracellular domains of Fc<sub>Y</sub> are also useful in this context to produce a response which mimics the response of a stimulated T-cell (see e.g., Eshhar et al., Proc. Nat. Acad. Sci. USA 90: 720 (1993)). The ability to generate a T-cell clone having: 1) a predetermined MHC/peptide ligand specificity; and 2) the ability to mimic activity of cytotoxic T lymphocyte following binding to the MHC/peptide ligand offers the opportunity for a new method of therapeutic intervention which is discussed in greater detail below.

If, on the other hand, a T-cell response which mimics the natural response of a stimulated T-cell is not required, a great variety of transmembrane/signaling domains can be used. Based on previous work with chimeric transmembrane receptors, it would be predicted with a high degree of certainty that the fusion of the extracellular domain of the single chain T-cell receptor of this invention, with the transmembrane/signaling domain of virtually any transmembrane receptor, would

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result in the production of a chimeric single chain T-cell receptor in which the signaling function would be operable following specific binding of the extracellular domain of the single chain T-cell receptor to the 5 MHC/peptide ligand for which it is specific.

For example, the intracellular and transmembrane domains of a tyrosine kinase receptor can be used. Many transmembrane tyrosine kinase receptors have been identified (for reviews see, e.g., Hanks, *Current 10 Opinion in Structural Biology* 1: 369 (1991) and Pawson and Bernstein, *Trends in Genetics* 6: 350 (1990)). Such a receptor, when stimulated, functions to phosphorylate intracellular protein targets. In this instance, an increase in intracellular phosphorylation could be 15 detected using specific antibodies (i.e., anti-phosphotyrosine antibodies such as antibody 4G10 which is available commercially from Upstate Biotechnology Incorporated) thereby providing a positive indication of specific binding of the self-signaling T-cell receptor 20 to its MHC/peptide ligand binding partner. Such a detection method would be useful, for example, in connection with a diagnostic embodiment of the present invention which is described below.

Preferably the self-signaling single chain T-cell 25 receptor is expressed in a T lymphocyte which is then clonally expanded. In theory, any T lymphocyte can be employed as a host-cell for expression of the self-signaling T-cell receptor. However, for many 30 applications, expression in a cytotoxic T lymphocyte is preferred. T lymphocytes to be used as host-cells can be purified from the peripheral blood cells of an individual. Alternatively, established T lymphocyte tumor cell lines can be employed. Many such tumor cell lines have been reported in the literature. Expression 35 is accomplished by the introduction of an expressible genetic construct carrying DNA encoding the self-signaling single chain T-cell receptor into the T lymphocyte. As discussed previously, the ability to

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design and synthesize such an expressible genetic construct is a matter of routine experimentation given the current state of the art.

5       The compositions described above are useful in a variety of contexts. For example, the single chain T-cell receptor and related compositions are useful in a method for diagnosing viral infection in a patient. In this method of diagnosis, a single chain T-cell receptor which binds specifically to an antigenic peptide from  
10      the virus when presented by an antigen presenting cell in association with an MHC is produced as described previously. To facilitate detection, the soluble T-cell receptor may be labeled with a reporter group (e.g., a radiolabeling group).

15      A peripheral blood cell preparation from the individual to be tested for viral infection is then incubated with the soluble single chain T-cell receptor under conditions appropriate for binding of the soluble single chain T-cell receptor to the MHC/peptide ligand for which it is specific. Such conditions include, for example, incubation in a physiologically compatible buffer at a temperature of about 4° C. Following an appropriate incubation period (e.g., 30 minutes) the cells are pelleted and resuspended in a wash solution to  
20      remove labeled single chain T-cell receptor which is not specifically complexed with an MHC/peptide ligand on the surface of antigen presenting cells.

25      Following the removal of non-specifically bound receptor, the amount of radiolabel associated with the cellular fraction is determined. This determination can be made using a variety of standard techniques depending upon the identity of the label employed. Values determined in this manner are then compared with values determined in an otherwise identical incubation using a  
30      peripheral blood cell preparation from an individual known to be noninfected with the virus of interest.  
35      Viral infection is indicated by the detection of substantially greater signal (i.e., at least about 2-

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fold) from the peripheral blood cell preparation from the individual to be tested for viral infection when compared with the signal detected using the peripheral blood cell preparation from the individual known to be  
5 noninfected.

The method of diagnosing viral infection discussed above can also be modified to employ a self-signaling T-cell receptor of the type described above. In this method of diagnosis it is not necessary that the signal produced by receptor binding to the MHC/peptide ligand result in a T-cell response which mimics the T-cell response in vivo (i.e., secretion of protein factors). Rather, all that is required is that specific binding of the self-signaling single chain T-cell receptor to the  
10 MHC/peptide ligand result in the generation of a specific and detectable signal. In light of this, the transmembrane/signaling domain of the self-signaling T-cell receptor can be selected from virtually any transmembrane receptor possessing both a transmembrane  
15 and a signaling domain. It will be recognized, of course, that the transmembrane/signaling domain from a transmembrane receptor known to participate in a signaling process which stimulates a T-cell response which mimics the T-cell response in vivo can be used.  
20 An example of such a transmembrane receptor is the CD3  
25  $\zeta$ -chain.

DNA encoding the self-signaling single chain T-cell receptor is introduced in expressible form into a mammalian T-cell. When incubated under conditions appropriate for metabolic activity, the self-signaling single chain T-cell receptor is expressed and displayed  
30 on the surface of the host-cell.

A peripheral blood cell preparation from an individual to be tested for infection is provided. The peripheral blood cell preparation is subsequently fixed in solution using a fixing agent (e.g., paraformaldehyde). In addition to providing other  
35

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experimental advantages, fixing the antigen presenting cell ensures that any cytokine secretion subsequently detected is secreted from the T-cell. Following a wash step to remove excess fixing agent, the fixed cells and  
5 the cells bearing the self-signaling single chain T-cell receptor are incubated together under conditions appropriate for binding of a T-cell receptor to the MHC/peptide target for which it is specific.

Specific binding of the self-signaling single chain T-cell receptor to the MHC/peptide ligand for which it is specific results in a triggering of the signaling domain of the self-signaling receptor. Signal is then detected by conventional techniques. For example, if the signaling domain is from a tyrosine kinase receptor,  
10 signal is detected using anti-phosphotyrosine antibodies. If, on the other hand the signaling domain is from a transmembrane receptor having the properties CD3  $\gamma$ -chain, signal is detected for example by the detection of secreted lymphokine (e.g., IL-2) using  
15 appropriate immunological reagents. The level of signal determined is then compared with levels determined in an otherwise identical experiment using a peripheral blood cell preparation from an individual known to be noninfected.  
20

In addition to the diagnostic applications discussed above, the soluble single chain T-cell receptor of the present invention (and the self-signaling counterpart) can be used in a therapeutic context. Soluble T-cell receptors with proper  
25 specificity, either alone or with another functional group (such as toxins) can be used to block specific immune response or target malignant or virus-infected cells. The self-signaling single chain T-cell receptor, when expressed in a suitable host-cell, can be applied  
30 to regulate specific immune response or to target malignant or virus-infected cells.  
35

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The single chain design of the T-cell receptors of this invention will also facilitate the construction of T-cell receptor phage libraries similar to those made for single chain antibodies (Clackson et al, Nature 352: 5 624 (1992)). The success in producing a bacterially-expressed three-domain single chain design supports this application. Such libraries are powerful tools for the isolation of T-cell receptors with defined specificity and/or high affinity.

10

EXAMPLE 1

The present example discloses studies in which different single chain T-cell receptor designs were evaluated in transfected eukaryotic cells with respect to surface expression of T-cell receptor molecules, proper folding and recognition of the appropriate MHC/peptide ligand. A single-chain three-domain construct ( $V\alpha$ -linker- $V\beta$ - $C\beta$ ) was stably expressed on the 15 cell surface when linked to a glycosyl-phosphatidyl-inositol (GPI) anchor and recognized by a conformation dependent mAb specific for the  $V\beta 17$  segment. The soluble form of this recombinant protein could be readily obtained by enzymatic cleavage with 20 phosphatidyl-inositol-specific phospholipase C (PI-PLC). Replacement of the GPI domain with the cytoplasmic portion of the  $\zeta$ -chain resulted in a functional T-cell receptor molecule that transduced an intracellular 25 signal following recognition of the proper MHC/peptide ligand and the superantigen staphylococcal enterotoxin B (SEB).

30 cDNAs of T-cell receptor  $\alpha$  and  $\beta$  chains were prepared from mRNA of 2H9 cells with Superscript reverse transcriptase (BRL) and an oligo(dT) primer (Sigma) and 35 were amplified by PCR using Vent DNA polymerase (New England Biolabs) and primers 5'- GCTCGAGGCAGCGATGGAAACTCTCCTGGGAGT-3' (A5) (SEQ ID NO. 4)

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and 5'-GGAATTCAAGCTGGACCAAGCCGC-3' (SEQ ID NO. 5) for  $\alpha$  chain and 5'-GCTCGAGCTCTGCCATGGACTCCTGG-3' (SEQ ID NO. 6) and 5'-GGAATTCAAGAAATCCTTCCTCTTGAC-3' (SEQ ID NO. 7) for  $\beta$  chain. The cDNAs were cloned into the mammalian expression vector pBJ-neo (Engel et al., *Science* 256: 1318 (1992)). GPI-anchored T-cell receptor molecules ( $\alpha$ -PI and  $\beta$ -PI) were constructed as follows. A Ban I site was engineered after the fifth amino acid residue beyond the last cysteine by oligonucleotide-directed mutagenesis. The region 3' of the Ban I site was then replaced with a Ban I-Not I fragment encoding the GPI signal domain from the human placental alkaline phosphatase. For the construction of various single chain T-cell receptors, variable domains of the 2H9 T-cell receptor  $\alpha$  and  $\beta$  chains were prepared by PCR using primers A5 and 5'-CAGAGCTCACGGATGAACAATAAGGCTGGT-3' (SEQ ID NO. 8) for the V $\alpha$  domain in all the single chain T-cell receptor constructs, 5'-TCGGATATCGATGGTGGAAATCACTCAGTCC-3' (B5) (SEQ ID NO. 9) and 5'-CAGAGATCAGCACGGTGAGCCGGTTCCC-3' (SEQ ID NO. 10) for the V $\beta$  domain in AB-PI-1, 5'GTGGGAGATCTCTGCTTCTGATGGCTCAAAC (SEQ ID NO. 11) and B5 for the V $\beta$  domain in AB-PI-2, 5'-CACGGATCCCCGTCTGCTCTACCCAGGC (SEQ ID NO. 12) and B5 for the V $\beta$  and C $\beta$  domains in ABC-PI, and 5'-CACGGATCCCCGTCTGCTCTACCCAGGC-3' (SEQ ID NO. 13) and B5 for the V $\beta$  and C $\beta$  domains in ABC- $\gamma$ . The cDNA encoding the transmembrane and cytoplasmic domains of murine CD3  $\gamma$  chain (Engel et al., *Science* 256: 1318 (1992)) was employed. Convenient restriction sites were engineered at the end of each fragment to aid in the assembly of the construct. The linker was a 15-amino acid motif of GGGGS repeated three times (Huston et al., *Int. Rev. Immunol.* 10: 195 (1992)) with Sac I at the 5' end and EcoRV at the 3' end. Except for  $\alpha$ -PI, all the constructs were cloned into pBJ-neo, which carries the G418-resistance gene.  $\alpha$ -PI was cloned into pCEP-4

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(Invitrogen), which bears the hygromycin-resistance gene. All constructs were verified by multiple restriction digests and by sequencing with the Sequenase kit (United States Biochemical).

5 Recombinant T-cell receptor molecules were generated by using the T-cell receptor  $\alpha$ - and  $\beta$ -chain sequences of the human myelin basic protein (MBP) specific T-cell clone Hy.2H9 (Wucherpfennig et al., *Science* 248: 1016 (1990); Wucherpfennig et al., *J. Immunol.* 152: 5581 (1994)). This clone T-cell receptor is composed of the V $\alpha$ 3.1 and V $\beta$ 17.1 segments and is specific for the immunodominant MBP peptide MBP-(85-99) in the context of HLA-DR2 (DRA, DRB1\*1602) (Wucherpfennig et al., *J. Immunol.* 152: 5581 (1994)).

10 Usage of the V $\beta$ 17.1 segment allowed the proper folding of recombinant T-cell receptors to be probed using the superantigen SEB (Choi et al., *Proc. Natl. Acad. Sci. USA* 86: 8941 (1989)) and the monoclonal antibody C1 (Friedman et al., *J. Exp. Med.* 174: 891 (1991)). To confirm the V $\beta$ 17 specificity of C1, the extracellular domains of T-cell receptor  $\alpha$  and  $\beta$  chains of Hy.2H9 cells were fused to the C-terminal sequence from human placental alkaline phosphatase for GPI anchorage (Fig. 1) and the DNAs encoding the GPI-anchored  $\beta$  and  $\alpha$  chains (B-PI and  $\alpha$ -PI) were sequentially transfected by electroporation into a T-cell receptor  $\alpha$ - and  $\beta$ -chain-deficient murine lymphoma cell line, BW5147  $\alpha^-\beta^-$  (BW) (White et al., *J. Immunol.* 143: 1822 (1989)). The surface expression of the GPI-anchored T-cell receptor chains was monitored by staining with mAbs  $\alpha$ F1 (Henry, et al., *Hybridoma* 8: 577 (1990)),  $\beta$ F1 (Brenner et al., *J. Immunol.* 138: 1502 (1987)), and C1.  $\alpha$ F1 and  $\beta$ F1 recognize nonconformational epitopes located in the C region of the T-cell receptor  $\alpha$  and  $\beta$  chains,

15 respectively. Surface expression of the T-cell receptor  $\beta$  chain is independent of heterodimer formation and assembly of the CD3 complex (Lin et al., *Science* 249:

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677 (1990)). In the  $\beta$ -PI-transfected cells, high-level expression of  $\beta$ -PI was confirmed by staining with  $\beta$ F1. Interestingly, there was little C1 staining of these transfectants. However, when a GPI-anchored 2H9  $\alpha$  chain 5 was supertransfected into the  $\beta$ -PI transfectant, C1 reactivity was greatly increased while the level of  $\beta$ F1 staining remained constant. Thus, the V $\beta$ 17-specific C1 epitope is conformational and dependent on the proper pairing of T-cell receptor  $\alpha$  and  $\beta$  chains and can 10 therefore be used to assess the proper folding of recombinant T-cell receptors bearing a V $\beta$ 17 sequence.

High-level expression of the T-cell receptor  $\alpha$  chain ( $\alpha$ -PI) was, however, not stable either alone or in the presence of  $\beta$ -PI. Attempts were made on several 15 cell lines, including COS-7, CHO-K1, and a T-cell receptor-deficient variant of Jurkat-cells, JK- $\beta^-$  (J.RT3-T3.5, American Type Culture Collection). The expression level of  $\alpha$ -PI was comparable to that of  $\beta$ -PI after the initial drug selection, but continued culture for less 20 than a month yielded a population of cells with little surface express of  $\alpha$ -PI, whereas  $\beta$ -PI expression was stable. The inability to obtain cell lines with stable high-level expression of the PI-anchored human T-cell receptor  $\alpha$  chain has been reported previously (Devaux et 25 al., *Eur. J. Immunol.* 21: 2111 (1991)).

To overcome the limitation set by the unstable expression of the human T-cell receptor  $\alpha$  chain, various sc designs were examined. Initially, a design similar to that of sc antibodies (Fv) was chosen (Huston et al., 30 *Int. Rev. Immunol.* 10: 195 (1992)). A 15-residue flexible linker was used to link the C terminus of the V $\alpha$ -J $\alpha$  domain to the N terminus of the  $\beta$  chain. The GPI domain was then ligated to the C terminus of the V $\beta$ -J $\beta$  domain. The construct (AB-PI-1, Fig. 1) was transfected 35 into several cell lines, including JK- $\beta^-$ , COS-7, CHO-K1, and BW. Although the expression of the gene was confirmed by the detection of the correct RNA

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transcripts, no surface expression was detected, as evidenced by negative C1 antibody staining.

Immunoprecipitation after metabolic labeling failed to recover any C1-reactive sc molecules from these

5 transfectants. The inability to identify any C1-reactive protein could have been due to the design of this molecule, such as insufficient linker length between the extracellular domain and the GPI domain. To improve the accessibility of the sc construct, another

10 two-domain single chain T-cell receptor was designed in which an extra 30-amino acid portion of the N terminus of the C $\beta$  domain was added as a hinge region. The transfectants of this construct (AB-PI-2, Fig. 1) were still not reactive with the C1 antibody. Finally, the

15 entire C $\beta$  domain was added to the sc construct. A complete C $\beta$  domain should provide enough distance for the V $\alpha$ -V $\beta$  domains to be expressed on the cell surface and, more importantly, should allow surface expression to be monitored with another antibody,  $\beta$ F1 (Brenner et al., *J. Immunol.* 138: 1502 (1987)). This three-domain sc T-cell receptor was constructed by extending the T-cell receptor  $\beta$ -chain sequences to the residue right before the last cysteine (the sixth cysteine), which was then fused to the GPI domain. The last cysteine was

20 deleted to prevent dimerization between C $\beta$  domains.

25 This construct (ABC-PI, Fig. 1) was transfected into BW cells and surface expression was confirmed by staining with both  $\beta$ F1 and C1. Both antibodies stained the cells with comparable efficiency, suggesting that most of the

30 molecules were expressed in the correct conformation. Moreover, the molecule could be efficiently cleaved from the cell surface with PI-PLC.

Soluble three-domain single chain T-cell receptor was purified from transfectants after PI-PLC cleavage

35 followed by affinity chromatography using the  $\beta$ F1 antibody. More specifically, after transfection and G418 selection (Engel et al. *Science* 256: 1318 (1992)),

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cells expressing a high level of GPI-linked three-domain single chain T-cell receptor (ABC-PI) were isolated by three rounds of sorting. The resulting cells were grown in spinner culture to a density of  $10^6$  per ml and harvested by centrifugation. The pellet was washed twice with phosphate-buffered saline (PBS) and resuspended in PBS containing 2 mM Pefabloc protease inhibitor (•••) (Centerchen, Inc., Stamford, CT) to a density of  $5 \times 10^7$  per ml with PI-PLC (Sigma) added at 1 unit/ml. Cells were incubated at 37°C for 1 hr with constant rocking. The supernatant was collected by centrifugation and by passage through a 0.45-μm filter and applied to a column of Acti-gel (•••) (Sterogen, Inc., Arcadia, CA) with immobilized βF1. The column was washed with 10 volumes of PBS and the soluble T-cell receptor was eluted with 0.15 M glycine (pH 2.8). Fractions were immediately neutralized with 0.1 volume of saturated Tris. The soluble T-cell receptor was then dialyzed against > 100 volumes of PBS at 4°C with at least four changes and concentrated to 0.5 mg/ml by vacuum dialysis against PBS. Five micrograms of purified soluble three-domain single chain T-cell receptor was analyzed by SDS/PAGE under reducing conditions.

The purified three-domain single chain T-cell receptor appeared as multiple bands at 50-70 kDa after SDS/PAGE. The observed heterogeneity of single chain T-cell receptor is probably the result of variable glycosylation; its polypeptide size calculated from amino acid composition is 40 kDa. The structural integrity of the three-domain single chain T-cell receptor was verified by a two-antibody ELISA. The molecules were first captured by the βF1 antibody immobilized to the plate and then assessed for reactivity with the C1 antibody. When compared with the three-domain single chain T-cell receptor produced in a bacterial expression system, the single chain T-cell

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receptor from the eukaryotic system gave 10-20 times higher C1 reactivity. The purified three-domain single chain T-cell receptor was stable and could be stored in PBS at 4°C for months without significant loss of C1  
5 reactivity.

To directly assess the functional integrity of the three-domain single chain T-cell receptor, a self-signaling single chain T-cell receptor was produced by replacing the GPI domain with the transmembrane and  
10 cytoplasmic domains of the CD3  $\gamma$  chain. These regions have been shown to be sufficient for signal transduction when its extracellular fusion partner is crosslinked by an antibody or by the proper ligand (Engel et al.  
Science 256: 1318 (1992); Irving et al., Cell 64: 891  
15 (1991); Romeo et al., Cell 64: 1037 (1991)). To enable the recovery of three-domain single chain T-cell receptor as a soluble form, a linker containing a thrombin cleavage site was inserted into the junction of three-domain single chain T-cell receptor and the  $\gamma$   
20 domain. The construct (ABC- $\gamma$ ) was transfected into BW cells and the rat basophilic leukemia cell line RBL-2H3 (RBL) (Engel et al. Science 256: 1318 (1992)), and the populations displaying high-level expression of three-domain single chain T-cell receptor were isolated by  
25 three rounds of cytofluorometric sorting using the antibody  $\beta$ F1. The ABC- $\gamma$ -transfected cells were first stimulated with various antibodies to confirm the self-signaling nature of this recombinant molecule.

More specifically, ABC- $\gamma$ -transfected BW5147 $\beta$   $\alpha\beta^-$   
30 cells ( $5 \times 10^4$  per well) were cultured in a 96-well round-bottom plate to which various antibodies had been immobilized (1  $\mu$ g per well). The supernatants were collected after 24 hr and interleukin 2 (IL-2) production was assessed in a bioassay using an IL-2-dependent-cell line (CTLL) and the CellTiter-96 nonradioactive proliferation assay (Promega). In the  
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case of ABC- $\zeta$ -transfected RBL-2H3 (Engel et al., *Science* 256: 1318 (1992)) cells, the cells were incubated with [ $^3$ H]serotonin (NEN) at 0.5  $\mu$ Ci (18.5 kBq) for 24 hr before they were added to the antibody plate. After 5 incubation at 37°C for 2 hr, radioactivity released into the supernatant was measured in a liquid scintillation counter. The specific serotonin release was calculated as described (Engel et al., *Science* 256: 1318 (1992)). For SEB stimulation,  $5 \times 10^4$  transfected cells per well 10 were cultured with various concentrations of SEB (Toxin Technology, Madison, WI) in the presence or absence of  $2 \times 10^5$  B cells. For antigen presentation,  $5 \times 10^4$  transfected cells per well were cocultured with  $2 \times 10^5$  B 15 cells which were incubated with or without the myelin basic protein (MBP)-(85-89) peptide for 3 hr before the experiment. The assays were conducted as described above.

Both transfectants showed a strong response following  $\beta$ F1 and C1 stimulation but not to purified 20 mouse immunoglobulin or anti-CD8 antibody used as controls. The structural integrity of the single chain T-cell receptor was further examined with the superantigen SEB, which binds to both V $\beta$ 17 and MHC class II molecules, resulting in T-cell receptor crosslinking 25 and T-cell activation regardless of the peptide bound to the MHC molecule (Choi et al., *Proc. Natl. Acad. Sci. USA* 86: 8941 (1989); Irwin et al., *Immunol. Rev.* 131: 61 (1993)). ABC- $\zeta$  transfectants displayed a concentration-dependent response toward SEB when the superantigen was 30 presented by transformed B-cell lines with high-level expression of DR1 (DRA, DRB1\*0101; cell line LG2) or DR2 (DRA, DRB1\*1602; cell line 9016). Thus, the lateral face of the T-cell receptor V $\beta$  region to which SEB is thought to bind (Choi et al., *Nature (London)* 346: 471 35 (1990)) is structurally intact.

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To prove that the three-domain single chain T-cell receptor did indeed recognize the MHC/peptide ligand, antigen presentation experiments using the natural ligand for the 2H9 clone, 9016 cells bearing the DRB1\*1602 allele of DR2, and MBP-(85-99) peptide were performed. To ensure detection of subtle abnormalities in the structure of the three-domain single chain T-cell receptor, 9009 cells (DRA, DRB1\*1601), which also bind MBP-(85-89), were used as a control. DRB1\*1601 and DRB1\*1602 differ only at position 67 in the DR $\beta$ 1 domain; this T-cell receptor contact-residue substitution does, however, abolish recognition of the peptide by the parent T-cell clone (Wucherpfennig, et al, *J. Immunol.* 152: 5581 (1994)). The ABC- $\zeta$  transfected BW<sup>+</sup> cells secreted IL-2 in response to peptide-pulsed 9016 cells, but not to peptide-pulsed 9009 cells. Similar results were obtained with RBL transfectants, as serotonin release was dependent on the concentration of the MBP peptide used to pulse 9016 cells. The signal appeared to be weak when compared with antibody stimulation. This is not surprising, however, since saturating amounts of antibodies are expected to crosslink the majority of T-cell receptor molecules on the target-cell, whereas a much smaller fraction of T-cell receptor molecules is probably engaged when T-cells are cocultured with peptide-pulsed antigen-presenting cells, in which a maximum of 5-15% of the DR molecules bind the peptide. The requirement for a high concentration of peptide or SEB is not due to the sc design, since high concentrations of peptide are also needed to stimulate  $\alpha\beta$  heterodimers of the T-cell receptor- $\zeta$  constructs (Engel et al. *Science* 256: 1318 (1992)). It is likely that the decrease in sensitivity results from the lack of CD3, CD4, and/or other adhesion/signaling molecules. Nonetheless these results demonstrate that the three-domain single chain T-cell receptor was correctly folded and functionally competent. In addition, a soluble form

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of three-domain single chain T-cell receptor could be obtained from the ABC- $\zeta$  transfectants by thrombin cleavage and affinity purification.

5

EXAMPLE 2

Materials and Methods

i) Construction of the single chain T-cell receptors

Recombinant T-cell receptor molecules were generated using the T-cell receptor  $\alpha$  and  $\beta$  chain sequences of the human myelin basic protein (MBP) specific T-cell clone Hy.2H9 as described in Example 1. This T-cell receptor is composed of the V $\alpha$ 3.1 and V $\beta$ 17.1 segments and is specific for the immunodominant MBP(85-99) peptide in the context of HLA-DR2 (DRA, DRB1\*1602). cDNAs for the T-cell receptor  $\alpha$  and  $\beta$  chains of the Hy.2H9 cells were prepared as described in Example 1. DNA fragments corresponding to the variable or constant domains of the  $\alpha$  and  $\beta$  chains were prepared by PCR using cDNA template with convenient restriction sites engineered at the ends of each fragment. The  $\alpha$  and  $\beta$ -chain domains were connected by a 15-residue peptide linker with the primary sequence of GGGGS GGGGS GGGGS (SEQ ID NO. 14) (Huston et al., Proc. Natl. Acad. Sci. USA 85: 5879 (1988)). The assembled single chain T-cell receptor was cloned in frame into a bacterial expression vector with PelB signal sequence and an isopropyl  $\beta$ -D-thiogalactopyronoside (IPTG) inducible Tac promoter. The nucleotide sequence of the final construct was confirmed using the Sequenase sequencing kit (USB) and the complete sequence is shown in SEQ ID NO: 1.

ii) Expression, purification and refolding of the single chain T-cell receptors

To induce expression of single chain T-cell receptors, E. coli strain BMH transformed with the single chain T-cell receptor plasmid was grown in Luria

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broth containing 15  $\mu\text{g}/\text{ml}$  tetracycline and 2% glucose (w/v) at 30°C to a density at  $A_{600}$  of 0.5 to 1.0. Cells were then pelleted by centrifugation and washed once with Luria broth. The cells were resuspended in fresh  
5 Luria broth containing 1 mM IPTG, grown for a further 8-12 hours at 37°C before being harvested by centrifugation. The cell pellet was resuspended in 10 ml/3g cell paste of 50 mM Tris-HCl (pH 8.0)/1 mM EDTA/lysozyme (1 mg/ml)/1 mM phenylmethylsulfonyl  
10 fluoride (PMSF) and incubated on ice for 30 min. DNase and MgCl<sub>2</sub> were added to final concentrations of 10  $\mu\text{g}/\text{ml}$  and 10 mM respectively and the suspension was incubated for 30 min at room temperature. EDTA was added to a concentration of 20 mM and the suspension was subjected  
15 to 2 cycles of freeze/thaw. An additional 20 mM MgCl<sub>2</sub> was added to the suspension and incubated at room temperature for a further 15 min. After addition of EDTA to a final concentration of 40 mM, the cell suspension was centrifuged at 10,000 xg for 30 min at 4°C. The supernatant was removed and the cell pellet containing inclusion bodies was washed twice with 0.5% Triton X-100/50 mM Tris-HCl (pH 8.0)/100 mM NaCl/0.1% sodium azide. After a final wash in 50 mM Tris-HCl (pH 8.0)/100 mM NaCl, the pellet containing inclusion bodies  
20 was solubilized in 8M urea/100 mM NaHPO<sub>4</sub>/10 mM Tris-HCl (urea buffer) (pH 8.0). The suspension was centrifuged at 10,000 xg for 30 min, and the supernatant was loaded onto a Ni-NTA column (Qiagen) and washed with 10 volumes of urea buffer (pH 8.0) and then 5 volumes of urea  
25 buffer (pH 6.3). Protein was eluted in fractions from the column in 2 volumes of urea buffer (pH 4.5). Protein content was determined by a Coomassie blue protein assay, and fractions containing proteins were pooled and diluted in refolding buffer to a protein  
30 concentration of 50  $\mu\text{g}/\text{ml}$ . The final refolding buffer contained 3M urea/50 mM Tris-HCl (pH 8.0)/1 mM EDTA/0.3 mM oxidized glutathione/3 mM reduced glutathione/1 mM  
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PMSF. The refolding solution was incubated at 4°C with gentle mixing for 48 hours and then dialyzed against 100 volume of PBS at 4°C with at least 4 changes. Refolded protein was first concentrated in an Amicon stir cell 5 with a YM10 membrane to a volume of 25-50 ml, then further concentrated by vacuum dialysis against PBS.

iii) Affinity purification of corrected folded proteins

The protein solution was cleared by passage through 10 a 0.45 µm filter and applied to a column of Acti-gel (Sterogen) with immobilized C1 (Friedman et al., *J. Exp. Med.* 174: 891 (1991)). The column was washed with 10 volumes of PBS and the single chain T-cell receptor was eluted with 0.15 M glycine (pH 2.8). Fractions were 15 immediately neutralized with 1/10 volume of saturated Tris. The single chain T-cell receptor was then dialyzed against more than 100 volumes of PBS at 4°C with at least 4 changes and concentrated to 0.5 mg/ml by vacuum dialysis against PBS.

20

iv) ELISA

For the two-antibody ELISA, βF1 (Brenner et al., *J. Immunol.* 138: 1502 (1987)) was immobilized on a 94-well ELISA plate (200 ng/well) by incubating in 50 mM bicarbonate buffer (pH 9.5) overnight at 4°C. After 25 blocking with PBS containing 3% BSA (Sigma) and 0.05% Tween-20 at room temperature for 1 hour, single chain T-cell receptor preparations were added in serial dilution. Wells were washed with PBS containing 0.05% Tween-20, followed by the addition of biotinylated C1 30 antibody. Binding was detected with streptavidin-conjugated alkaline phosphatase (Sigma) after the addition of substrate (Bio-rad). Absorbence at 410 nm was determined using a 96-well plate reader. For the 35 direct-binding ELISA, soluble T-cell receptors in serial dilution were immobilized on the plate. After the blocking step, C1 antibody was added to the wells

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followed by an alkaline phosphatase conjugated anti-mouse immunoglobulin antibody. The binding was measured after the addition of the substrate as described above.

5    Results

The present example relates to the expression of a three-domain single chain T-cell receptor in bacteria. The final construct for bacterial expression bears a three-domain design similar to its eukaryotic counterpart described in Example 1, with a few modifications. More specifically, the N-terminal endogenous  $\alpha$ -chain leader sequence was deleted, a histidine tag was added to the C-Terminus for convenient purification with Ni-NTA resin and additional amino acid residues created convenient restriction sites at these junction regions. This three-domain single chain T-cell receptor was cloned into a bacterial expression vector in frame with a N-terminal PelB signal sequence. The presence of the PelB sequence was intended to allow recombinant proteins to be expressed as secretory proteins and to be isolated from either the growth medium or the periplasmic space. However, it was determined that the yield from these preparations was extremely low and the majority of the proteins were accumulated in bacteria as inclusion bodies. Based on these observations, the three-domain single chain T-cell receptors were isolated from inclusion bodies. The recombinant proteins were subsequently purified with a one-step Ni-NTA chromatography procedure through the binding of histidine tag engineered at its C-terminus. SDS-PAGE analysis of the induction of the three-domain single chain T-cell receptor, the inclusion body preparation, the flowthrough of the NI-NTA column and purified proteins eluted from the column was performed. In general, 5-10 mg of the recombinant protein could be purified from each liter of bacteria culture.

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The purified protein which was reduced and denatured following the NI-NTA column chromatography step was subsequently refolded with glutathione. The efficiency of refolding was evaluated with a two-  
5 antibody ELISA where the fraction of C1 reactive protein was measured. Previously, C1 had been demonstrated to recognize a V $\beta$ <sub>17</sub> specific epitope. Further, it had been shown and that the formation of this epitope is dependent upon the proper folding and pairing of the T-cell receptor  $\alpha$  and  $\beta$  chains. The eukaryotically expressed three-domain single chain T-cell receptor was used as a control in the two-antibody ELISA. The eukaryotically produced single chain T-cell receptor was purified from the cell surface after the PI-PLC cleavage  
10 and likely consists of T-cell receptors completely folded in their native conformation. Based on a determination of C1 reactivity between the two preparations, 5-10% of the bacterially-expressed three-domain single chain T-cell receptor was properly folded.  
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20 To confirm the importance of the C $\beta$  domain, a two-domain single chain T-cell receptor based on the design of scFv was constructed and purified in the manner described above in connection with the three-domain single chain T-cell receptor. The folding of the two-  
25 domain T-cell receptor was assayed by direct-binding ELISAs with the C1 antibody. The bacterially expressed three-domain single chain T-cell receptor was used as a control. Refolded proteins were either directly immobilized to an ELISA plate or through the binding of Ni molecule which was coated on the bottom of the wells.  
30 The results of both studies demonstrate that, while the three-domain single chain T-cell receptor showed significant C1 reactivity, the two-domain single chain T-cell receptor was unable to interact with the C1 antibody even at high concentration. This is consistent  
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with observations following eukaryotic expression which highlight the importance of C $\beta$  domain in this single chain design.

The C1 reactive fraction of the bacterially  
5 expressed three-domain single chain T-cell receptor can  
be further separated from the refolded protein solution  
using a C1-affinity column. Consistent with the result  
from the two-antibody ELISA, 5-10% of the protein was  
recovered from the C1 column. Additionally, the C1  
10 purified three-domain single chain T-cell receptor  
appeared as a single band in a non-reduced SDS-PAGE, in  
contrast to the multiple bands observed from the  
refolded protein solution. Furthermore, in a two-  
antibody ELISA, the C1 purified protein displayed  
15 comparable C1 reactivity to the eukaryotically expressed  
three-domain single chain T-cell receptor preparation.

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SEQUENCE LISTING

**(1) GENERAL INFORMATION:**

- (i) APPLICANT: The President and Fellows of Harvard College
- (ii) TITLE OF INVENTION: SINGLE CHAIN T-CELL RECEPTOR
- (iii) NUMBER OF SEQUENCES: 14
- (iv) CORRESPONDENCE ADDRESS:
  - (A) ADDRESSEE: Kevin M. Farrell, P.C.
  - (B) STREET: P.O. Box 999
  - (C) CITY: York Harbor
  - (D) STATE: Maine
  - (E) COUNTRY: USA
  - (F) ZIP: 03911
- (v) COMPUTER READABLE FORM:
  - (A) MEDIUM TYPE: Floppy disk
  - (B) COMPUTER: IBM PC compatible
  - (C) OPERATING SYSTEM: PC-DOS/MS-DOS
  - (D) SOFTWARE: PatentIn Release #1.0, Version #1.25
- (vi) CURRENT APPLICATION DATA:
  - (A) APPLICATION NUMBER:
  - (B) FILING DATE:
  - (C) CLASSIFICATION:
- (vii) PRIOR APPLICATION DATA:
  - (A) APPLICATION NUMBER: 08/349,915
  - (B) FILING DATE: 06-DEC-1994
  - (C) CLASSIFICATION:
- (viii) ATTORNEY/AGENT INFORMATION:
  - (A) NAME: Farrell, Kevin M.
  - (B) REGISTRATION NUMBER: 35,505
  - (C) REFERENCE/DOCKET NUMBER: HU-9404 WO
- (ix) TELECOMMUNICATION INFORMATION:
  - (A) TELEPHONE: 207-363-0558
  - (B) TELEFAX: 207-363-0528

**(2) INFORMATION FOR SEQ ID NO:1:**

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 1176 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear
- (ii) MOLECULE TYPE: cDNA
- (ix) FEATURE:
  - (A) NAME/KEY: CDS
  - (B) LOCATION: 1..1176
- (xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

ATG AAA TAC CTA TTG CCT ACG GCA GCC GCT GGA TTG TTA TTA CTC GCT Met Lys Tyr Leu Leu Pro Thr Ala Ala Ala Gly Leu Leu Leu Leu Ala	48
1                   5                   10                   15	
GCC CAA CCA GCG ATG GCG GAT CTC CAA CAG GGA GAG GAG GAT CCT CAG Ala Gln Pro Ala Met Ala Asp Leu Gln Gln Gly Glu Glu Asp Pro Gln	96
20                25                30	

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GCC TTG AGC ATC CAG GAG GGT GAA AAT GCT ACC ATG AAC TGC AGT TAC Ala Leu Ser Ile Gln Glu Gly Glu Asn Ala Thr Met Asn Cys Ser Tyr 35 40 45	144
AAA ACT AGT ATA AAC AAT TTA CAG TGG TAT AGA CAA AAT TCA GGT AGA Lys Thr Ser Ile Asn Asn Leu Gln Trp Tyr Arg Gin Asn Ser Gly Arg 50 55 60	192
GGC CTT GTC CAC CTA ATT TTA ATA CGT TCA AAT GAA AGA GAG AAA CAC Gly Leu Val His Leu Ile Leu Ile Arg Ser Asn Glu Arg Glu Lys His 65 70 75 80	240
AGT GGA AGA TTA AGA GTC ACG CTT GAC ACT TCC AAG AAA AGC AGT TCC Ser Gly Arg Leu Arg Val Thr Leu Asp Thr Ser Lys Lys Ser Ser Ser 85 90 95	288
TTG TTG ATC ACG GCT ACC CGG GCA GCA GAC ACT GCT TCT TAC TTC TGT Leu Leu Ile Thr Ala Thr Arg Ala Ala Asp Thr Ala Ser Tyr Phe Cys 100 105 110	336
GCT ACG GAT ACA GGA GGA AGC TAC ATA CCT ACA TTT GGA AGA GGA ACC Ala Thr Asp Thr Gly Gly Ser Tyr Ile Pro Thr Phe Gly Arg Gly Thr 115 120 125	384
AGC CTT ATT GTT CAT CCG AGC TCT GGT GGC GGT GGG TCG GGC GGT GGT Ser Leu Ile Val His Pro Ser Ser Gly Gly Gly Ser Gly Gly Gly 130 135 140	432
GGC TCG GGT GGC GGC GGA TCG GAT ATC GAT GGT GGA ATC ACT CAG TCC Gly Ser Gly Gly Ser Asp Ile Asp Gly Gly Ile Thr Gln Ser 145 150 155 160	480
CCA AAG TAC CTG TTC AGA AAG GAA GGA CAG AAT GTG ACC CTG AGT TGT Pro Lys Tyr Leu Phe Arg Lys Glu Gly Gln Asn Val Thr Leu Ser Cys 165 170 175	528
GAA CAG AAT TTG AAC CAC GAT GCC ATG TAC TGG TAC CGA CAG GAC CCA Glu Gln Asn Leu Asn His Asp Ala Met Tyr Trp Tyr Arg Gln Asp Pro 180 185 190	576
GGG CAA GGG CTG AGA TTG ATC TAC TAC TCA GAG ATA GTA AAT GAC TTT Gly Gln Gly Leu Arg Leu Ile Tyr Tyr Ser Glu Ile Val Asn Asp Phe 195 200 205	624
CAG AAA GGA GAT ATA GCT GAA GGG TAC AGC GTC TCT CGG GAG AAG AAG Gln Lys Gly Asp Ile Ala Glu Gly Tyr Ser Val Ser Arg Glu Lys Lys 210 215 220	672
GAA TCC TTT CCT CTC ACT GTG ACA TCG GCC CAA AAG AAC CCG ACA GCT Glu Ser Phe Pro Leu Thr Val Thr Ser Ala Gln Lys Asn Pro Thr Ala 225 230 235 240	720
TTC GGG CCA GGG AAC CGG CTC ACC GTG CTA GAG GAC CTG AAA AAC GTG Phe Gly Pro Gly Asn Arg Leu Thr Val Leu Glu Asp Leu Lys Asn Val 245 250 255	768
TTC CCA CCC GAG GTC GCT GTG TTT GAG CCA TCA GAA GCA GAG ATC TCC Phe Pro Pro Glu Val Ala Val Phe Glu Pro Ser Glu Ala Glu Ile Ser 260 265 270	816
CAC ACC CAA AAG GCC ACA CTG GTG TGC CTG GCC ACA GGT ATC TTC CCT His Thr Gln Lys Ala Thr Leu Val Cys Leu Ala Thr Gly Ile Phe Pro 275 280 285	864
GAC CAC GTG GAG CTG AGC TGG TGG GTG AAT GGG AAG GAG GTG CAC AGT Asp His Val Glu Leu Ser Trp Trp Val Asn Gly Lys Glu Val His Ser 290 295 300	912

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GGG GTC AGC ACG GAC CCG CAG CCC CAC AAG GAG CAG CCC GCC CTC AAT Gly Val Ser Thr Asp Pro Gln Pro His Lys Glu Gln Pro Ala Leu Asn 305 310 315 320	960
GAC TCC AGA TAC TGC CTG AGC AGC CGC CTG AGG GTC TCG GCC ACC TTC Asp Ser Arg Tyr Cys Leu Ser Ser Arg Leu Arg Val Ser Ala Thr Phe 325 330 335	1008
TGG CAG AAC CCC CGC AAC CAC TTC CGC TGT CAA GTC CAG TTC TAC GGG Trp Gln Asn Pro Arg Asn His Phe Arg Cys Gln Val Gln Phe Tyr Gly 340 345 350	1056
CTC TCG GAG AAT GAC GAG TGG ACC CAG GAT AGG GCC AAA CCC GTC ACC Leu Ser Glu Asn Asp Glu Trp Thr Gln Asp Arg Ala Lys Pro Val Thr 355 360 365	1104
CAG ATC GTC AGC GCC GAG GCC TGG GGT AGA GCA GAT ATC GAG GGT AGG Gln Ile Val Ser Ala Glu Ala Trp Gly Arg Ala Asp Ile Glu Gly Arg 370 375 380	1152
ATC CAT CAC CAT CAC CAT CAC TAA Ile His His His His His 385 390	1176

## (2) INFORMATION FOR SEQ ID NO:2:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 391 amino acids
  - (B) TYPE: amino acid
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

Met Lys Tyr Leu Leu Pro Thr Ala Ala Ala Gly Leu Leu Leu Leu Ala 1 5 10 15
Ala Gln Pro Ala Met Ala Asp Leu Gln Gln Gly Glu Glu Asp Pro Gln 20 25 30
Ala Leu Ser Ile Gln Glu Gly Glu Asn Ala Thr Met Asn Cys Ser Tyr 35 40 45
Lys Thr Ser Ile Asn Asn Leu Gln Trp Tyr Arg Gln Asn Ser Gly Arg 50 55 60
Gly Leu Val His Leu Ile Leu Ile Arg Ser Asn Glu Arg Glu Lys His 65 70 75 80
Ser Gly Arg Leu Arg Val Thr Leu Asp Thr Ser Lys Lys Ser Ser Ser 85 90 95
Leu Leu Ile Thr Ala Thr Arg Ala Ala Asp Thr Ala Ser Tyr Phe Cys 100 105 110
Ala Thr Asp Thr Gly Gly Ser Tyr Ile Pro Thr Phe Gly Arg Gly Thr 115 120 125
Ser Leu Ile Val His Pro Ser Ser Gly Gly Gly Ser Gly Gly Gly 130 135 140
Gly Ser Gly Gly Gly Ser Asp Ile Asp Gly Gly Ile Thr Gln Ser 145 150 155 160

-35-

Pro Lys Tyr Leu Phe Arg Lys Glu Gly Gln Asn Val Thr Leu Ser Cys			
165	170	175	
Glu Gln Asn Leu Asn His Asp Ala Met Tyr Trp Tyr Arg Gln Asp Pro			
180	185	190	
Gly Gln Gly Leu Arg Leu Ile Tyr Tyr Ser Glu Ile Val Asn Asp Phe			
195	200	205	
Gln Lys Gly Asp Ile Ala Glu Gly Tyr Ser Val Ser Arg Glu Lys Lys			
210	215	220	
Glu Ser Phe Pro Leu Thr Val Thr Ser Ala Gln Lys Asn Pro Thr Ala			
225	230	235	240
Phe Gly Pro Gly Asn Arg Leu Thr Val Leu Glu Asp Leu Lys Asn Val			
245	250	255	
Phe Pro Pro Glu Val Ala Val Phe Glu Pro Ser Glu Ala Glu Ile Ser			
260	265	270	
His Thr Gln Lys Ala Thr Leu Val Cys Leu Ala Thr Gly Ile Phe Pro			
275	280	285	
Asp His Val Glu Leu Ser Trp Trp Val Asn Gly Lys Glu Val His Ser			
290	295	300	
Gly Val Ser Thr Asp Pro Gln Pro His Lys Glu Gln Pro Ala Leu Asn			
305	310	315	320
Asp Ser Arg Tyr Cys Leu Ser Ser Arg Leu Arg Val Ser Ala Thr Phe			
325	330	335	
Trp Gln Asn Pro Arg Asn His Phe Arg Cys Gln Val Gln Phe Tyr Gly			
340	345	350	
Leu Ser Glu Asn Asp Glu Trp Thr Gln Asp Arg Ala Lys Pro Val Thr			
355	360	365	
Gln Ile Val Ser Ala Glu Ala Trp Gly Arg Ala Asp Ile Glu Gly Arg			
370	375	380	
Ile His His His His His			
385	390		

**(2) INFORMATION FOR SEQ ID NO:3:**

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 32 amino acids
  - (B) TYPE: amino acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:3:

Leu Ala Pro Pro Ala Gly Thr Thr Asp Ala Ala His Pro Gly Arg Ser			
1	5	10	15

Val Val Pro Ala Leu Leu Pro Leu Leu Ala Gly Thr Leu Leu Leu			
20	25	30	

**(2) INFORMATION FOR SEQ ID NO:4:**

- (i) SEQUENCE CHARACTERISTICS:

-36-

- (A) LENGTH: 33 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:4:

GCTCGAGGCG GCGATGGAAA CTCTCCTGGG AGT

33

(2) INFORMATION FOR SEQ ID NO:5:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 24 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:5:

GGAATTCAAGC TGGACCACAG CCGC

24

(2) INFORMATION FOR SEQ ID NO:6:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 27 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:6:

GCTCGAGCTC TGCCATGGAC TCCTGGA

27

(2) INFORMATION FOR SEQ ID NO:7:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 26 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:7:

GGAATTCAAGA AATCCTTTCT CTTGAC

26

(2) INFORMATION FOR SEQ ID NO:8:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 30 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:8:

CAGAGCTCAC GGATGAACAA TAAGGCTGGT

30

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(2) INFORMATION FOR SEQ ID NO:9:

(i) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 30 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:9:

TCGGATATCG ATGGTGGAAT CACTCAGTCC

30

(2) INFORMATION FOR SEQ ID NO:10:

(i) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 28 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:10:

CAGAGATCAG CACGGTGAGC CGGTTCCC

28

(2) INFORMATION FOR SEQ ID NO:11:

(i) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 31 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:11:

GTGGGAGATC TCTGCTTCTG ATGGCTAAA C

31

(2) INFORMATION FOR SEQ ID NO:12:

(i) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 29 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:12:

CACGGATCCC CGTCTGCTCT ACCCCAGGC

29

(2) INFORMATION FOR SEQ ID NO:13:

(i) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 29 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:13:

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CACGGATCCC CGTCTGCTCT ACCCCAGGC

29

(2) INFORMATION FOR SEQ ID NO:14:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 15 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: peptide

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:14:

Gly Gly Gly Ser Gly Gly Gly Ser Gly Gly Gly Ser  
1 5 10 15

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CLAIMS

1. A single chain T-cell receptor which binds specifically to an MHC/peptide ligand.
2. The single chain T-cell receptor of Claim 1 wherein the MHC/peptide ligand is located on the surface of an antigen presenting cell.
3. The single chain T-cell receptor of Claim 1 which is soluble in an aqueous solution.
4. The single chain T-cell receptor of Claim 1 which is a 3-domain single chain T-cell receptor comprising an  $\alpha$  chain variable domain, a  $\beta$  chain variable domain and a constant domain.
5. The single chain T-cell receptor of Claim 4 wherein the  $V\alpha-J\alpha$  domain of the  $\alpha$  chain variable domain is linked to the N-terminus of the  $\beta$  chain variable domain by a flexible amino acid linker and the C-terminal region of the  $\beta$  chain variable domain is linked to the  $\beta$  chain constant domain.
6. A self-signaling single chain T-cell receptor which binds specifically to an MHC/peptide ligand, the self-signaling T-cell receptor comprising:
  - a) a soluble T-cell receptor domain comprising an  $\alpha$  chain variable domain, a  $\beta$  chain variable domain and a constant domain; and
  - b) a transmembrane and intracellular signaling domain from a transmembrane receptor.

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7. The self-signaling single chain T-cell receptor of Claim 6 wherein the V $\alpha$ -J $\alpha$  domain of the  $\alpha$  chain variable domain is linked to the N-terminus of the  $\beta$  chain variable domain by a flexible amino acid linker; the C-terminal region of the  $\beta$  chain variable domain is linked to the  $\beta$  chain constant domain; and the C-terminal region of the  $\beta$  chain constant region is linked to the N-terminal portion of the transmembrane and intracellular signaling domain of the transmembrane receptor.
8. The self-signaling single chain T-cell receptor of Claim 6 wherein the transmembrane receptor is selected from the group consisting of CD3  $\zeta$ -chain or Fc $_{\gamma}$ .
9. A nucleic acid molecule encoding a single chain T-cell receptor which binds specifically to an MHC/peptide ligand.
10. A nucleic acid molecule of Claim 9 which is soluble in an aqueous solution.
11. A nucleic acid molecule of Claim 9 which encodes a 3-domain single chain T-cell receptor comprising an  $\alpha$  chain variable domain, a  $\beta$  chain variable domain and a constant domain.
12. The nucleic acid molecule of Claim 9 wherein the single chain T-cell receptor comprises the V $\alpha$ -J $\alpha$  domain of the  $\alpha$  chain variable domain is linked to the N-terminus of the  $\beta$  chain variable domain by a flexible amino acid linker and the C-terminal region of the  $\beta$  chain variable domain is linked to the  $\beta$  chain constant domain.

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13. A DNA expression construct comprising, in expressible form, a nucleic acid molecule encoding a single chain T-cell receptor which binds specifically to an MHC/peptide ligand.
14. The DNA expression construct of Claim 13 wherein the single chain T-cell receptor comprises the V $\alpha$ -J $\alpha$  domain of the  $\alpha$  chain variable domain linked to the N-terminus of the  $\beta$  chain variable domain by a flexible amino acid linker and the C-terminal region of the  $\beta$  chain variable domain linked to the  $\beta$  chain constant domain.
15. A eukaryotic cell transformed with a DNA expression construct, the DNA expression construct comprising, in expressible form, a nucleic acid molecule encoding a single chain T-cell receptor which binds specifically to an MHC/peptide ligand.
16. A prokaryotic cell transformed with a DNA expression construct, the DNA expression construct comprising, in expressible form, a nucleic acid molecule encoding a single chain T-cell receptor which binds specifically to an MHC/peptide ligand.
17. A nucleic acid molecule encoding a self-signaling single chain T-cell receptor which binds specifically to an MHC/peptide ligand, the self-signaling single chain T-cell receptor comprising an  $\alpha$  chain variable domain, a  $\beta$  chain variable domain, a constant domain and a transmembrane and intracellular signaling domain from a transmembrane receptor.

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18. A DNA expression construct comprising, in expressible form, a nucleic acid molecule encoding a self-signaling single chain T-cell receptor which binds specifically to an MHC/peptide ligand, the self-signaling single chain T-cell receptor comprising:
  - a) a soluble T-cell receptor domain comprising an  $\alpha$  chain variable domain, a  $\beta$  chain variable domain and a constant domain; and
  - b) a transmembrane and intracellular signaling domain from a transmembrane receptor.
19. A eukaryotic cell transformed with a DNA expression construct comprising, in expressible form, a nucleic acid molecule encoding a self-signaling single chain T-cell receptor which binds specifically to an MHC/peptide ligand, the self-signaling single chain T-cell receptor comprising:
  - a) a soluble T-cell receptor domain comprising an  $\alpha$  chain variable domain, a  $\beta$  chain variable domain and a constant domain; and
  - b) a transmembrane and intracellular signaling domain from a transmembrane receptor.
20. The eukaryotic cell of Claim 19 which is a T-cell.
21. The eukaryotic cell of Claim 19 which is a killer T-cell.
22. A method for diagnosing viral infection in a patient, comprising:
  - a) providing a soluble T-cell receptor which binds specifically to an MHC/peptide ligand wherein the peptide component is a viral specific T-cell epitope;

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- b) incubating the soluble T-cell receptor of step a) with antigen presenting cells isolated from the patient under conditions appropriate for binding of the soluble T-cell receptor to the MHC/peptide ligand; and
- c) detecting specific binding of the soluble T-cell receptor to the MHC/peptide complex on the surface of the antigen presenting cells, specific binding being indicative of viral infection.

23. A method for diagnosing infection using a cell bearing chimeric transmembrane receptor comprising a 3-part single chain T-cell receptor fused to a transmembrane region and an intracellular signaling domain from a transmembrane receptor, comprising:

- a) providing antigen presenting cells from a patient;
- b) fixing the antigen present-cells with a fixing agent;
- c) providing a self-signaling T-cell clone which binds to a predetermined antigen, the self signaling T-cell clone comprising a T-cell bearing a self-signaling T-cell receptor on its cell surface, the self-signaling T-cell receptor comprising a 3-part T-cell receptor fused to a transmembrane region and an intracellular signaling domain from a transmembrane receptor;
- d) incubating the fixed antigen presenting cells from step b) and the self-signaling T-cell clone of step c) under conditions appropriate for T-cell receptor binding to MHC/peptide ligand; and
- e) detecting signal as an indication of the presence of the predetermined antigen on the surface of the antigen presenting cells in association with MHC.

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24. The method of Claim 23 wherein the T-cell clone is derived from a normal T-cell isolated from the patient.
25. The method of Claim 23 wherein the T-cell clone is derived from a benign tumor cell line.
26. The method of Claim 23 wherein the MHC is type I or type II.

1 / 1

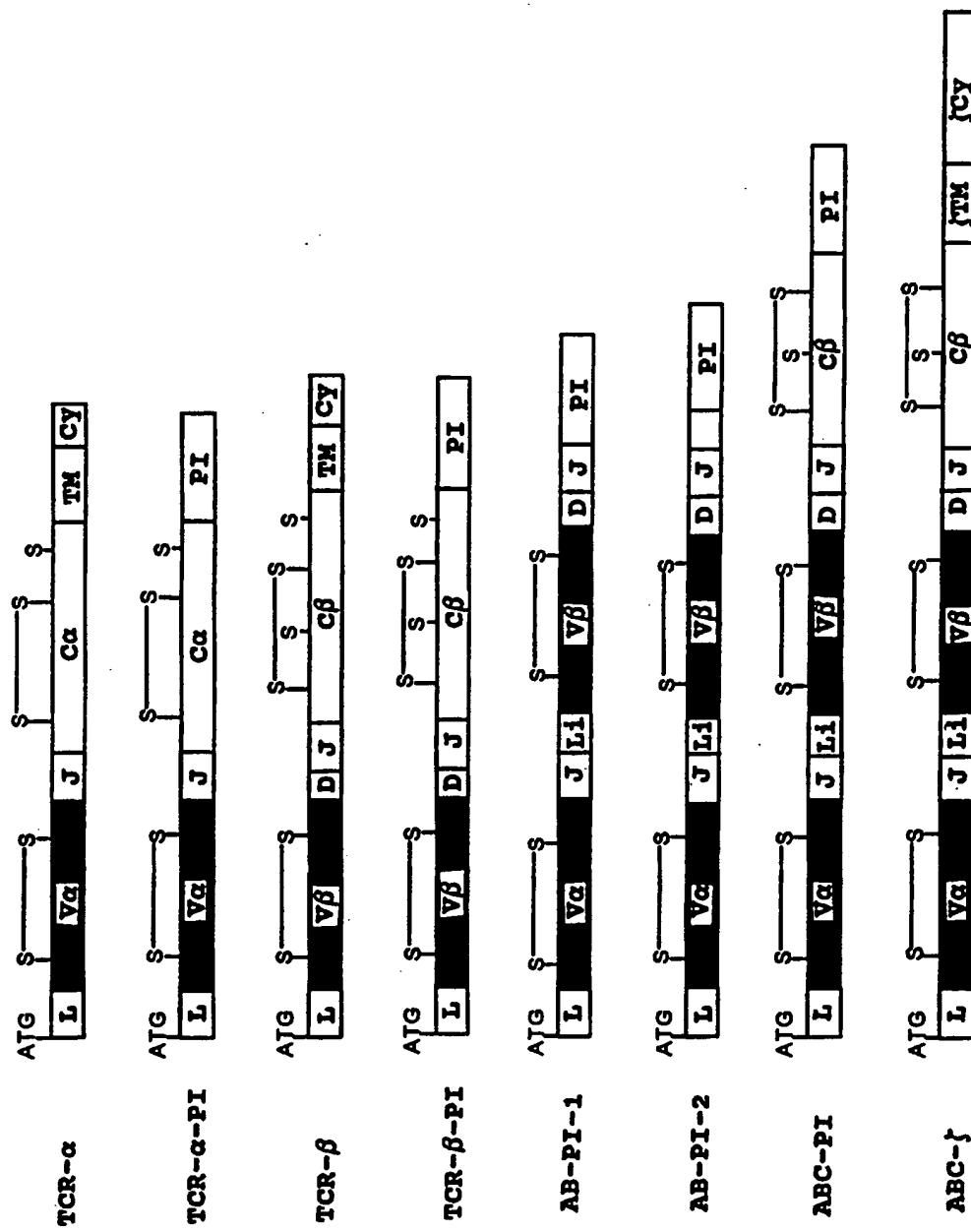


FIGURE 1

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US95/15696

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :Please See Extra Sheet.  
US CL :435/7.2, 69.7, 240.2, 252.3, 320.1; 536/23.4; 530/350  
According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 435/7.2, 69.7, 240.2, 252.3, 320.1; 536/23.4; 530/350

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS, MEDLINE, BIOSIS, World Patents Index  
search terms: T cell receptors, TCR, fusion, chimer?, single chain

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Proceedings of the National Academy of Science USA, Volumn 91, September 1994, V HILYARD et al., "Binding of Soluble Natural Ligands to a Soluble Human T-cell Receptor Fragment Produced in Escherichia coli", pages 9057-9061, see especially pages 9058-9060.	1-3, 9, 10, 13, 16
---		-----
Y		6-8, 17-21
X	WO, A, 91/18019 (E.R. SQUIBB AND SONS, INC.) 28 November 1991, pages 6, 10, 13, 19 and 40-44.	1-3, 9, 10, 13, 15, 16, 22
---		-----
Y		6-8, 17-21, 23-26

Further documents are listed in the continuation of Box C.  See patent family annex.

- \* Special categories of cited documents:
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  - "A" document defining the general state of the art which is not considered to be part of particular relevance
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  - "P" document published prior to the international filing date but later than the priority date claimed
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "Z" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 MARCH 1996	28 MAR 1996
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer  KAREN E. BROWN
Faxsimile No. (703) 305-3230	Telephone No. (703) 308-0196

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US95/15696

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 5,359,046 (CAPON et al.) 25 October 1994, column 8, line 11 to column 12, line 25.	6-8, 17-21, 23-26
Y ---	Annual Review of Biochemistry, Volume 59, 1990, DAVIS, "T CELL RECEPTOR GENE DIVERSITY AND SELECTION" pages 475-496, see especially pages 478-479 and Figures 2 and 3.	6-8, 17-21, 23-26 ----- 4, 5, 11, 12, 14
A		

**INTERNATIONAL SEARCH REPORT**

International application No.  
PCT/US95/15696

**A. CLASSIFICATION OF SUBJECT MATTER:**  
**IPC (6):**

G01N 33/566; C12P 21/02; C12N 1/21, 5/10, 15/12, 15/63, 15/70, 15/85; C07K 14/725

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